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Carbohydrate-loading prior to distance events is a common practice among endurance athletes. The purposes of this paper are to review previous research and to clarify misconceptions which may exist concerning carbohydrate-loading. The most effective method of carbohydrate-loading involves a training run of sufficient intensity and duration to deplete the muscle glycogen stores. This depletion run is followed by three days on a low carbohydrate diet (15 percent) with training maintained at 70-80 percent of usual mileage. On days four through seven the diet should be changed to one high (80-85 percent) in carbohydrates and the training greatly reduced (10-15 percent of usual mileage). Several criticisms of this procedure are discussed and recommendations for the safe and prudent use of carbohydrate-loading are presented. (Author)

CARBOHYDRATE-LOADING: A SAFE AND EFFECTIVE METHOD OF IMPROVING ENDURANCE PERFORMANCE

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ABSTRACT

CARBOHYDRATE-LOADING: A SAFE AND EFFECTIVE METHOD OF IMPROVING ENDURANCE PERFORMANCE

Carbohydrate-loading prior to distance events is a common practice among endurance athletes. The purposes of this paper are to review previous research and to clarify misconceptions which may exist concerning carbohydrate-loading. The most effective method of carbohydrate-loading involves a training run of sufficient intensity and duration to deplete the muscle glycogen stores. This depletion run is followed by three days on a low carbohydrate diet (15%) with training maintained at 70-80% of usual mileage. On days four through seven the diet should be changed to one high (80-85%) in carbohydrates and the training greatly reduced (10-15% of usual mileage). Several criticisms of this procedure are discussed and recommendations for the safe and prudent use of carbohydrate-loading are presented.

Manipulation of the glycogen overshoot phenomenon, or carbohydrate-loading, has gained widespread acceptance among distance runners in recent years. Still, some people remain skeptical, mainly due to misconceptions and a general lack of knowledge of how the process should be utilized. The purposes of this paper are to make the facts available to the reader and to clarify any misconceptions which may exist concerning carbohydrate-loading.

Astrand (2,3,5), after reviewing studies by Bergstrom and Hultman, reported that glycogen stores in the exercising muscles are a limiting factor in submaximal (75-85% $\dot{V}O_2$ max) aerobic endurance events. Bergstrom and Hultman supported this idea with a study of men who were fed three types of diets. Their findings indicated that a high carbohydrate diet resulted in higher levels of muscle glycogen and enabled the subjects to exercise at 75 percent of $\dot{V}O_2$ max for as much as three times longer before exhaustion (4).

Further research revealed that higher levels of glycogen storage were achieved by first depleting the muscles by strenuous exercise and then eating a diet high in carbohydrates. The largest increase in glycogen storage resulted from a regimen which involved depletion of the muscles, followed by a low carbohydrate diet for three days, and then switching to a high carbohydrate diet for three days (4).

Sheehan (19) speculated that the latter method of glycogen storage is probably an evolutionary adaptation to early man's dependence on a high fat and protein diet for several days as they gorged on the kill. This roughly corresponds to the first three days following glycogen depletion. The cavemen would then be reduced to living on fruits and berries until they could repeat their successful hunt. The fruits and berries, being high in carbohydrates, restored the glycogen in their muscles to even higher levels than before, and they were prepared for another exhausting hunt.

Studies indicate that carbohydrate-loading will enhance performance in long distance running events. Karlsson and Saltin (14) found that, when runners were subjected to two separate thirty-kilometer races (one following mixed diet, one following carbohydrate-loading), the mean improvement due to the diet was 7.7 minutes. In a survey of marathon (26 miles, 385 yards) runners, Slovic (21) reported improvements of up to sixteen minutes.

Increased glycogen supplies seem to make little difference during the initial 60-90 minutes of exercise, due to the fact that normal stores of glycogen should be sufficient (7,13,18). However, the diet may facilitate significant changes over the final portion of races lasting longer than 90 mintues, where athletes with greater stores of glycogen tend to maintain pace while other competitors slow considerably (9,14,20).

The classic carbohydrate-loading process begins with a long "depletion workout". As the name implies, this workout should be of sufficient intensity and duration to facilitate a state of glycogen depletion in the muscles. Studies reveal that a working time of between two and three hours brings about optimum results (11,15). Glycogen depletion is a localized phenomenon and only occurs in the muscles that are utilized (5,9,15). Accordingly, the intensity of the depletion workout should be at, or near race pace to ensure that the muscle fibers which will need the energy stores in the future are the same ones which are being depleted (9,15). This is of great importance because specific muscle fibers will be depleted according to the intensity of the activity (5,9,11,15) and glycogen cannot be borrowed between muscle fibers whether they are slow twitch oxidative, fast twitch oxidative glycolytic or fast twitch glycolytic (9,11).

Immediately following the depletion workout, the athlete should adhere to a low carbohydrate diet for three days (2,3,10). Due to the diet dependence of glycogen storage, the low carbohydrate diet is depriving the muscle of the carbohydrates needed to replenish energy reserves (5,10). The maintenance of a light workout schedule (70-80% of daily mileage) insures that no glycogen is stored. Forgac recommends that the diet during this period should include meat, fish, eggs, salad, poultry, cheese and small amounts of vegetables and breads. Liquids, along with water, may include whole milk, diet sodas and unsweetened tea. Every effort should be made to sustain a nutritionally adequate diet even though it may be low (15% of total caloric intake) in carbohydrates (10,15).

The athlete and coach must work closely together in maintaining a depleted state. During this period the body is in a weakened condition and may be susceptible to illness and injury (10,15). Accumulation of ketones in the body may occur due to the body's utilization of fats as an energy source (15). A high concentration of ketones not only causes a disagreeable breath odor, but may also put an unnecessary strain on the kidneys. Hypoglycemia, brought about by the depletion, may cause a depression of the nervous system as evidenced by headaches, dizziness and local muscular fatigue. All of these conditions should be prevented by constant ingestion of small amounts of carbohydrates and large volumes of water (6,10,15).

A sustained depleted state creates a craving for glycogen. The body has been without glycogen for so long that a glycogen storage enzyme (glycogen synthetase) is probably over-produced and the body's regulatory mechanisms are temporarily impaired. Still, because glycogen production is diet dependent, no change occurs as a low carbohydrate diet is maintained (9). The small amount of carbohydrate that is consumed is probably used by the liver for maintenance of the nervous system (3,15).

On the fourth day the diet is modified so that it now consists of a high percentage (80-85%) of carbohydrates (2,3,10,15). Glycogen supercompensation now begins with the muscles storing up as much carbohydrate as possible (8,10,15). Training should be minimized (10-15% of daily mileage) or even ceased during this three day period in order to prevent further depletion of stores (2,3,10,15). Most subjects state that the high carbohydrate phase of the diet is very enjoyable both physically and mentally, because the craving for carbohydrates may now be answered and the hard training is finished (8,12).

The diet during "repletion" should consist of fruits and fruit juices, along with breads, cereals, rice, vegetables, pasta and various types of carbohydrates. Beverages, along with water and fruit juice, may include chocolate milk, sweetened coffee and sodas (8,10). Throughout the three days total caloric intake should remain relatively constant. Carbohydrates should constitute a large percentage of the total dietary intake, but the subject should not overeat (10,15). Fluid intake should remain well above normal (10,15,17).

The dietary intake should be curtailed during the final 2-4 hours prior to the event. Maximum super-compensation should have occurred during the preceding three days and further ingestion could only hamper performance. Evidence suggests that no significant drop in glycogen stores occurs in the final hours before the event, even with no caloric intake (8,10,15).

The dramatic increase in the number of participants in endurance type athletic events has spawned a desire for an easy means of attaining success in running, biking and multi-sport events such as triathlons. The carbohydrate-loading diet was thought by many to be the panacea for which they had been searching. Unwary athletes eagerly anticipated an opportunity to improve performance times and carelessly experimented with the diet without knowing its scientific basis or specific guidelines. Thus medical problems developed and carbohydrate-loading was assumed to be the cause.

Closer examination has revealed that a majority of the problems were caused, not by the diet itself, but by a general misunderstanding of its principles. Due to the lack of available information many important guidelines were not followed, resulting in serious complications such as dehydration and ECG irregularities (15,16).

Mirkin (16) reported a case in 1973 of a runner who experienced chest pains and electrocardiogram modifications while utilizing the high carbohydrate phase of the diet. The ECG showed flattening, inversion of the T wave, and S-T segment depression, which indicated that some portion of the heart muscle was ischemic. However, nutritional assessment revealed that the runner had been eating as much bread as could be ingested for the entire three day period. The patient consumed almost two loaves at one meal, an intake that is unrealistic for any diet! Following a reduction in caloric intake the patient's pain subsided and the ECG returned to normal. Certainly, no cause and effect relationship has been established between gorging on bread and ECG abnormalities. The example is simply used to reinforce the fact that common sense and caution should be used when undertaking carbohydrate-loading.

Another potential hazard of the process may be dehydration (15). Research reveals that for every gram of glycogen which is stored in the muscle there is a corresponding storage of approximatley 2.7 grams of water (1-3,10,15,17). The water retention which is necessary to facilitate this storage may cause a state of dehydration in other tissues unless it is offset by an increased ingestion of fluids (10,15).

Storage of large amounts of glycogen and water in muscles may bring about a feeling of stiffness in the legs (2,6,10,14,15,17) However, refraining from "loading" for this reason would be equivalent to not filling a car's fuel tank due to the hinderance of added weight. Breakdown and aerobic metabolism of one gram of glycogen liberates more than three grams of water (6,15). This liberated water may prove to be helpful to the runner, especially in the area of thermoregulation and sweat loss during long distance races in hot, humid environments (6,10,15).

A majority of runners who have successfully utilized the classic carbohydrate-loading process tend to continue to use it (8,12). Ron Wayne, a former national marathon champion, and Don Kardong, fourth place finisher in the 1976 Olympic marathon, both credit carbohydrate-loading as one of the keys to their success. Ron Hill, British marathoner, is known to have been carbohydrate-loading as long ago as the early 1960's, at which time he was almost unbeatable.

However, though the classic carbohydrate-loading regimen has exhibited success, it is not recommended for use on a weekly or even a monthly basis. The low carbohydrate phase of the diet places such a severe strain on the body that it is recommended for use only 2-3 times per year. It also seems that if this regimen is used more often than is recommended, the low carbohydrate phase loses its ability to enchance the glycogen storage capacity of the body (9).

Research by Sherman et al (20) indicates that the risky-low carbohydrate phase of the carbohydrate-loading regimen is unnecessary. Investigators found no significant difference between glycogen levels achieved using the low carbohydrate phase and levels using mixed (50% carbohydrate) diet during the first three days of the regimen. Training throughout the six-day sequence consisted of runs of 90,40,40,20 and 20 minutes at 73% of aerobic capacity with rest on the final day before the event. The investigators concluded that by using a tapering training sequence and less severe diet alterations glycogen may be supercompensated to levels comparable to those noted in previous studies, with less risk to the individual.

In summary, the carbohydrate-loading process is complicated and should not be attempted without first developing a thorough understanding of the prinicples involved. Both the classic carbohydrate-loading regimen, and recent variations upon it have exhibited capacity to facilitate improvements in work time to exhaustion. A thorough adherence to the guidelines presented in this paper should result in, not only an enhancement of performance in endurance events, but also a safe experience for the athlete.

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